(51) International Patent Classification 6 :		(11) International Publication Number:	**WO 98/36512**
H04B 10/00	A1	(43) International Publication Date:	20 August 1998 (20.08.98)

(21) International Application Number: PCT/US98/02641

(22) International Filing Date: 13 February 1998 (13.02.98)

(30) Priority Data:
08/799,365   14 February 1997 (14.02.97)   US

(71) Applicant: UNIVERSITY OF MARYLAND BALTIMORE COUNTY [US/US]; 5410 Wilkens Avenue, Baltimore, MD 21228 (US).

(72) Inventors: GOLOVCHENKO, Ekaterina, A.; 5138 Darting Bird Lane, Columbia, MD 21044 (US). PILIPETSKII, Alexei, N.; 5138 Darting Bird Lane, Columbia, MD 21044 (US). MENYUK, Curtis, R.; 13308 Locksley Lane, Silver Spring, MD 20904 (US).

(74) Agent: NATH, Gary, M.; Nath & Associates, Suite 750, 1835 K Street, N.W., Washington, DC 20006 (US).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

(54) Title: REDUCTION OF COLLISION INDUCED TIMING JITTER BY PERIODIC DISPERSION MANAGEMENT IN SOLITON WDM TRANSMISSION
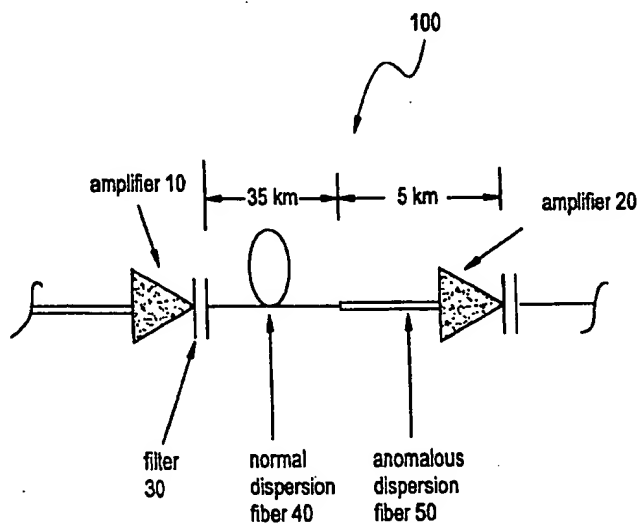
(57) Abstract

Collisions between solitons in different frequency channels are one of the major sources of errors in transmission systems that utilize wavelength division multiplexing (WDM). Moreover, because standard transmission lines have lumped amplification, the four-wave mixing fields from soliton collisions grow uncontrollably, adding amplitude and timing jitter to the jitter due to ideal soliton collisions. These problems are addressed by using specific dispersion map (100) to implement dispersion management, by which it is possible to significantly reduce the collision-induced timing jitter and to improve system performance even in comparison with that provided by an ideal, exponentially decreasing dispersion fiber (40).

REDUCTION OF COLLISION INDUCED TIMING JITTER BY PERIODIC DISPERSION MANAGEMENT IN SOLITON WDM TRANSMISSION

FIELD OF THE INVENTION

The present invention generally relates to a method
and apparatus for reducing errors in transmission systems
caused by collisions between solitons in different frequency
channels, and particularly in transmission systems that
utilize wavelength division multiplexing (WDM).

BACKGROUND OF THE INVENTION

Collisions between solitons in different frequency
channels are one of the major sources of errors in
transmission systems that utilize wavelength division
multiplexing (WDM). Moreover, because standard transmission
lines have lumped amplification, the four-wave mixing fields
from soliton collisions grow uncontrollably, adding amplitude
and timing jitter to the jitter due to ideal soliton
collisions. According to the present invention, these
problems are addressed by using proper dispersion management,
by which it is possible to significantly reduce the
collision-induced timing jitter and to improve system
performance even in comparison with that provided by an ideal,
exponentially decreasing dispersion fiber.

Further, the present invention may significantly improve
the performance of soliton communication systems
with both time

2

division multiplexing (TDM) and wavelength division
multiplexing (WDM).

The present technology of WDM soliton systems uses either
uniform dispersion fiber or dispersion decreasing
5   fiber.

Various devices and methods are known pertaining to
the transmission of solitons for use in telecommunications.
Additionally, wave division multiplexing (WDM) is known in the
field of telecommunications. Examples of such devices are
10   discussed further hereunder.

U.S. Patent No. 5,557,441 issued to Mollenauer discloses
a soliton transmission system having plural sliding-frequency
guiding filter groups to control timing jitter. The optical
filters are arranged in groups whose average center frequency
15   differs from the other groups along the length of the
transmission line. The groups are arranged so as to have
frequency increasing, frequency decreasing, and combinations
of both, to reduce noise while permitting transmission of
solitons.

20   U.S. Patent No. 5,471,333 issued to Taga et al.
discloses solitons, wherein wavelength dispersion is
controlled by a fiber having first sections which have an
average value of wavelength dispersion which is larger than
the dispersion value meeting with the soliton condition, and
25   second sections with an average value of the wavelength
dispersion smaller than the dispersion value meeting with the
soliton condition. The average value of the wavelength
dispersion of the entire length of the optical fiber
transmission line assumes a positive value.

U.S. Patent No. 5,579,428 issued to Evans et al. was cited for teaching a single mode optical waveguide fiber using soliton signal pulses with a dispersion flattened waveguide. This reference fails to teach periodic dispersion management,
5   nor does it address the problem of reduction of collision induced timing jitter, among other differences.

U.S. Patent No. 5,523,874 issued to Epworth discloses an optical soliton pulse transmission system that replaces passive optical filters with active optical filters. A loop
10   tunes the center frequency of the filter to provide a specific offset from the center frequency of the solitons.

U.S. Patent No. 5,504,829 issued to Evans et al. discloses soliton transmission in fiber having a refractive index that monotonically decreases along the
15   fiber.

U.S. Patent No. 5,550,671 issued to Simpson et al. discloses Wavelength Division Multiplexed (WDM) technology. Similarly, U.S. Patent No. 5,546,210 issued to Chraplyvy et al. discloses 4-wave mixing products with channel carriers and
20   WDM technology.

U.S. Patent No. 5,530,585 issued to Reid et al. discloses a dispersion shifted fiber for use in soliton optical transmission. U.S. Patent No. 5,469,525 issued to Luther-Davies et al. discloses dark spatial soliton
25   technology.

However, the foregoing references do not address the problem of reduction of collision induced timing jitter, and the use of periodic dispersion management to solve this problem. Further

the foregoing references do not address the problem of
improving soliton WDM transmission using periodic dispersion
management.

SUMMARY OF THE INVENTION

The present invention is directed to an optical
fiber and an apparatus useful in improving soliton WDM
transmission using periodic dispersion management. Further,
the present invention addresses the problem of reduction of
collision induced timing jitter, and employs periodic
dispersion management to solve this problem.

As discussed hereinabove, collisions between solitons in
different frequency channels are one of the major sources of
errors in transmission systems that utilize wavelength
division multiplexing (WDM). Moreover, because standard
transmission lines have lumped amplification, the four-wave
mixing fields from soliton collisions grow uncontrollably,
adding amplitude and timing jitter to the jitter due to ideal
soliton collisions. The present invention, by using proper
dispersion management, significantly reduces the
collision-induced timing jitter and improves system
performance even in comparison with that provided by an ideal,
exponentially decreasing dispersion fiber.

The present invention is based on the use of alternating-
sign dispersion management. A dispersion map is provided to
allow significant reduction of collision-induced timing jitter
in WDM systems. Such dispersion-managed fiber systems are
technologically easier to construct than is a system based on

5

dispersion-decreasing fibers. The dispersion map according to the present invention does not use any special fibers, and can be constructed from standard and dispersion-shifted fibers.

Furthermore, a particular feature of the present invention is that the dispersion map enables solitons to propagate through almost 90% of the path in normal dispersion fiber which in general does not support soliton propagation.

An object of the present invention is accordingly to improve the quality of information transmission, while at the same time improving the information capacity of the transmission fibers used.

Another object of the present invention is to improve both single and multiple channel soliton transmission.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel unfiltered WDM system, for a uniform dispersion fiber.

Fig. 1B illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel unfiltered WDM system, for a dispersion-decreasing fiber.

Fig. 1C illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel unfiltered WDM system, for a dispersion-managed fiber according to the present invention.

Fig. 1D is a chart of symbols used in Figs. 1A-1C versus channel number.

Fig. 2 is a schematic diagram of a dispersion map according to the present invention.

Fig. 3A illustrates the normalized pulse intensity of pulse trains in a demultiplexed 4th channel of an eight-channel unfiltered WDM system at 5,000 km, for a uniform dispersion fiber.

Fig. 3B illustrates the normalized pulse intensity of pulse trains in a demultiplexed 4th channel of an eight-channel unfiltered WDM system at 5,000 km, for a dispersion-decreasing fiber.

Fig. 3C illustrates the normalized pulse intensity of pulse trains in a demultiplexed 4th channel of an eight-channel unfiltered WDM system at 5,000 km, for a dispersion-managed fiber according to the present invention.

Fig. 4A illustrates the spectral intensity for the spectrum of the eight-channel unfiltered WDM system at 5,000 km, for a uniform dispersion fiber.

Fig. 4B illustrates the spectral intensity for the spectrum of the eight-channel unfiltered WDM system at 5,000 km, for a dispersion-decreasing fiber.

Fig. 4C illustrates the spectral intensity for the spectrum of the eight-channel unfiltered WDM system at 5,000 km, for a dispersion-managed fiber according to the present invention.

Fig. 5A illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel WDM system with in-line filtering, for a uniform dispersion fiber.

5   Fig. 5B illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel WDM system with in-line filtering, for a dispersion-decreasing fiber.

Fig. 5C illustrates the standard deviation of jitter in 10   soliton arrival times versus propagation distance for an eight-channel WDM system with in-line filtering, for a dispersion-managed fiber according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Figs. 1A-1C compare the standard deviation of jitter in 15   soliton arrival times versus propagation distance for an eight-channel unfiltered WDM system, for various types of fiber, as follows. Fig. 1A illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel unfiltered WDM system, for a uniform 20   dispersion fiber. Fig. 1B illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel unfiltered WDM system, for a dispersion-decreasing fiber. Fig. 1C illustrates the standard deviation of jitter in soliton arrival times versus 25   propagation distance for an eight-channel unfiltered WDM system, for a dispersion-managed fiber according

8

to the present invention. The symbols used in Figs. 1A-1C
correspond to channel numbers according to the chart in Fig.
1D. These figures are discussed further hereunder, with
reference also to Fig. 2, in which Fig. 2 is a schematic

5   diagram of a dispersion map according to the present
invention.

In Fig. 2, a dispersion map 100 is shown for a filter 30
and a normal dispersion fiber 40. A amplifier 10 is connected
to the filter 30, and the length of the normal dispersion

10   fiber 40 is approximately 35 km, and is followed by an
approximately 5 km length of anomalous dispersion fiber 50.
The anomalous dispersion fiber 50 is connected to an amplifier
20.

The present invention shown in Fig. 2 includes an

15   improved optical fiber and optical fiber arrangement having
improved periodic dispersion management, and an apparatus
useful in improving soliton WDM transmission using periodic
dispersion management. The present invention as shown reduces
collision induced timing jitter by use of periodic dispersion

20   management.

Collisions between solitons in different frequency
channels are one of the major sources of errors in
transmission systems that utilize wavelength division
multiplexing (WDM). Moreover, because standard transmission

25   lines have lumped amplification, the four-wave mixing fields
from soliton collisions grow uncontrollably, adding amplitude
and timing jitter to the jitter due to ideal soliton
collisions. The present invention employs dispersion
management to significantly reduce the collision-induced

30   timing jitter and thereby improve system performance,

even in comparison with that provided by an ideal, exponentially decreasing dispersion fiber.

The present invention is based on the use of alternating-sign dispersion management. A dispersion map as shown in Fig. 2 and described further hereunder, is provided to allow significant reduction of collision-induced timing jitter in WDM systems. The dispersion map according to the present invention does not use any special fibers, and can be constructed from standard and dispersion-shifted fibers.

Also, the dispersion map of the present invention enables solitons to propagate through almost 90% of the path in normal dispersion fiber which in general does not support soliton propagation. Further, both single and multiple channel soliton transmission can be used in the present invention.

The present invention uses dispersion management to reduce collision-induced timing jitter in soliton WDM transmission, and as a result the performance of dispersion managed fibers provides better performance that either dispersion-decreasing fibers and fibers with uniform dispersion. This is applicable both for filtered and unfiltered systems. This is discussed further hereunder.

A major source of errors in soliton wavelength-division-multiplexed (WDM) transmission is collision-induced timing jitter. Because standard transmission lines have lumped amplification, the four-wave mixing fields from soliton collisions grow uncontrollably even when the spacing between

amplifiers is much smaller than the soliton collision length,
adding amplitude and timing jitter to the jitter due to ideal
soliton collisions. It has been proposed in the technical
literature [P.V. Mamyshev and L.F. Mollenauer in Opt. Lett.

5   21, 397 (1996)] to use dispersion-decreasing fiber to reduce
the four-wave mixing fields. However, by the present
invention, dispersion management is shown to be a viable
alternative to dispersion-decreasing fiber.

     Remarkably, as discussed further hereunder, computational

10   results show that solitons in dispersion-managed fibers can
actually suffer less impairment than solitons in ideal
dispersion-decreasing fibers with the same average dispersion
when the channel spacing is less than about 10 pulse spectral
widths.

15   Dispersion-managed fibers, i.e., fibers with dispersion
maps that alternate in sign, have long been used in
non-return-to zero transmission. There has been recent
interest in also using dispersion management in soliton
transmission to suppress Gordon-Haus timing jitter by

20   decreasing the path-averaged value of dispersion [M. Suzuki,
I. Morita, S. Yamamoto, N. Edagawa, H. Taga, and S. Akiba,
Electron. Lett. 23, 2027 (1995)] and to suppress filtered
soliton instabilities in WDM [S. Wabnitz, Opt. Lett. 21, 638
(1996)].

25   Computer simulations of up to eight WDM soliton channels
were performed. Each such soliton channel was filled with
pseudo-random 32 bit sequences of 20 ps solitons spaced in
time

11

by 5 FWHM. The path-averaged dispersion was D = 0.5 ps/nm-km,
and the amplifier spacing was 40 km. For the system with no
in-line filtering, the amplifiers exactly compensated for the
fiber loss. For the filtered transmission system, Fabry-Perot
etalons were placed at the same location as amplifiers, and
the filter transmission frequency was shifted with a rate
close to the critical sliding rate [P.V. Mamyshev and L.F.
Mollenauer, Opt. Lett. 21, 397 (1996)]. The amplifier gain
for the filtered system was slightly increased to compensate
for additional losses introduced into the system by the
filters. In view of the calculating of the timing jitter from
soliton collisions, the Gordon-Haus timing jitter was not
included. To reduce the initial partial collision the soliton
sequences in neighboring channels were shifted by half a time
slot. It was found that a single channel in a fiber with
uniform dispersion has transmission characteristics that are
indistinguishable from a dispersion decreasing fiber with an
ideal exponential taper. These calculations showed that when
the WDM channels are spaced by 12 pulse spectral widths, the
dispersion-decreasing fiber has the smallest jitter, but the
performance of the dispersion-managed fiber is much better
than the uniform dispersion fiber. This is shown in the
following discussion with respect to Figs. 1-5.

Fig. 1 shows the calculated standard deviation of the
tuning jitter σ versus transmission distance for an
eight-channel WDM system with channels spaced by 6 pulse
spectral widths. The

12

specific fibers under study included a fiber with uniform
dispersion, a dispersion decreasing fiber with an ideal
exponential taper, and a periodically dispersion managed fiber
with the sign of the dispersion changing between the
5   amplifiers.

A dispersion map according to the present invention is
shown in Fig. 2. According to this dispersion map, a 35 km
fiber is provided with normal dispersion D_1 = -2 ps/nm-km
which is followed by a 5 km fiber with anomalous dispersion D_2
10   = 18 ps/nm-km to provide the average value of anomalous
dispersion D = 0.5 PS nm-km. In this case, the total length
of the dispersion map equals the amplifier spacing. According
to the present invention as shown in Fig. 2, the solitons in
dispersion-managed fibers suffer less impairment than solitons
15   in ideal dispersion-decreasing fibers with the same average
dispersion when the channel spacing is less than about 10
pulse spectral widths. Accordingly, the dispersion-managed
fiber demonstrates the best performance.

For the unfiltered system, the timing jitter in the side
20   channels for the dispersion-decreasing fiber is low, but
drastic errors occur in the central channels. It is the
central channels that are the most strongly affected by the
collisions. By the present invention as shown in Figs. 1 and
2, it is possible by managing the dispersion to actually have
25   less timing jitter than is the case for ideal soliton
collisions.

The pulse train of the central channel for the unfiltered
system is shown in Figs. 3A-3C. As shown in Figs. 3A-3C, the

normalized pulse intensity of pulse trains are shown in a
demultiplexed 4th channel of an eight-channel unfiltered WDM
system at 5,000 km. In these figures, the pulse intensity is
normalized to the intensity of an average soliton in a
transmission line with lumped amplification.

In Fig. 3A, the normalized intensity is shown with
respect to time (ps) for a uniform dispersion fiber. In Fig.
3B, the normalized intensity is shown with respect to time
(ps) for a dispersion decreasing fiber. In Fig. 3C, the
normalized intensity is shown with respect to time (ps) for a
dispersion managed fiber.

As seen in Figs. 3A-3C, the amplitude jitter in the
dispersion-managed fiber (Fig. 3C) is larger than in the
dispersion-decreasing fiber (Fig. 3B).

Fig. 3A illustrates the normalized pulse intensity of
pulse trains in a demultiplexed 4th channel of an eight-
channel unfiltered WDM system at 5,000 km, for a uniform
dispersion fiber. Fig. 3B illustrates the normalized pulse
intensity of pulse trains in a demultiplexed 4th channel of an
eight-channel unfiltered WDM system at 5,000 km, for a
dispersion-decreasing fiber, and Fig. 3C illustrates the
normalized pulse intensity of pulse trains in a demultiplexed
4th channel of an eight-channel unfiltered WDM system at 5,000
km, for a dispersion-managed fiber according to the present
invention.

Fig. 4A illustrates the spectral intensity for the
spectrum of the eight-channel unfiltered WDM system at 5,000
km, for a

14

uniform dispersion fiber. Fig. 4B illustrates the spectral
intensity for the spectrum of the eight-channel unfiltered WDM
system at 5,000 km, for a dispersion-decreasing fiber. Fig.
4C illustrates the spectral intensity for the spectrum of the
5   eight-channel unfiltered WDM system at 5,000 km, for a
dispersion-managed fiber according to the present invention.

Further, as seen in Figs. 4A-4C, the power of a four-wave
mixing field in the dispersion-managed fiber (Fig. 4C) is
larger than in the dispersion-decreasing fiber (Fig. 4B).
10   Nevertheless, the dispersion-managed solitons are less
impaired overall.

The introduction of in-line filters decreases the
collision-induced timing jitter by a factor in a range of two
to three.

15   Fig. 5A illustrates the standard deviation of jitter in
soliton arrival times versus propagation distance for an
eight-channel WDM system with in-line filtering, for a uniform
dispersion fiber.

Fig. 5B illustrates the standard deviation of jitter in
20   soliton arrival times versus propagation distance for an
eight-channel WDM system with in-line filtering, for a
dispersion-decreasing fiber.

Fig. 5C illustrates the standard deviation of jitter in
soliton arrival times versus propagation distance for an
25   eight-channel WDM system with in-line filtering, for a
dispersion-managed fiber according to the present invention.

Figs. 5A-5C show the calculated standard deviation of the
timing jitter σ versus the transmission distance for an eight-

channel WDM system with channels spaced by 6 pulse spectral
widths for the case of the filtered system. As can be seen
from these figures, the dispersion managed system (Fig. 5C)
demonstrates the best performance.

5   The above result is particularly significant because it
is currently far easier to construct a dispersion-managed
system than it is to construct a system with an ideal
exponential taper. Moreover, by the present invention, it
should be possible to operate with lower average dispersion,

10   thus lowering the amount of timing jitter.

          The invention being thus described, it will be evident
that the same may be varied in many ways. Such variations are
not to be regarded as a departure from the spirit and scope of
the invention and all such modification are intended to be

15   included within the scope of the following claims.

16

What is claimed is:

1.   An apparatus for reducing errors in transmission
systems caused by collisions between solitons in different
frequency channels, comprising:

5   a telecommunications arrangement for soliton transmission
formed by a dispersion map which employs dispersion
management; and

        said dispersion map including a dispersion-managed fiber
system.

10   2.   An apparatus as claimed in claim 1, wherein said
dispersion-managed fiber system includes a normal dispersion
fiber connected to an anomalous dispersion fiber.

3.   An apparatus as claimed in claim 1, wherein said
dispersion-managed fiber system includes a filter connected to
15 a normal dispersion fiber.

4.   An apparatus as claimed in claim 1, wherein said
dispersion-managed fiber system includes an amplifier, a
filter connected to said amplifier, a normal dispersion fiber,
and an anomalous dispersion fiber connected to said normal
20 dispersion fiber.

17

5.   An apparatus as claimed in claim 1, wherein said
dispersion-managed fiber system includes an amplifier, a
filter connected to said amplifier, a normal dispersion fiber
having a length of approximately 35 km, and an anomalous
dispersion fiber having a length of approximately 5 km and
connected to said normal dispersion fiber.

6.   An apparatus for reducing errors in transmission
systems caused by collisions between solitons in different
frequency channels for use in transmission systems that
utilize wavelength division multiplexing, comprising:
        a telecommunications arrangement for soliton transmission
formed by a dispersion map which employs dispersion
management; and
        said dispersion map including a dispersion-managed fiber
system.

7.   An apparatus as claimed in claim 6, wherein said
dispersion-managed fiber system includes a normal dispersion
fiber connected to an anomalous dispersion fiber.

8.   An apparatus as claimed in claim 6, wherein said
dispersion-managed fiber system includes a filter connected to
a normal dispersion fiber.

18

9. An apparatus as claimed in claim 6, wherein said dispersion-managed fiber system includes an amplifier, a filter connected to said amplifier, a normal dispersion fiber, and an anomalous dispersion fiber connected to said normal dispersion fiber.

10. An apparatus as claimed in claim 6, wherein said dispersion-managed fiber system includes an amplifier, a filter connected to said amplifier, a normal dispersion fiber having a length of approximately 35 km, and an anomalous dispersion fiber having a length of approximately 5 km and connected to said normal dispersion fiber.

11. An apparatus for reducing errors in transmission systems caused by collisions between solitons in different frequency channels for use in transmission systems that utilize wavelength division multiplexing, comprising:

a telecommunications arrangement for soliton transmission formed by a dispersion map which employs dispersion management; and

said dispersion map including a dispersion-managed fiber system, to significantly reduce collision-induced timing jitter and to improve system performance in comparison with that provided by an ideal, exponentially decreasing dispersion fiber.

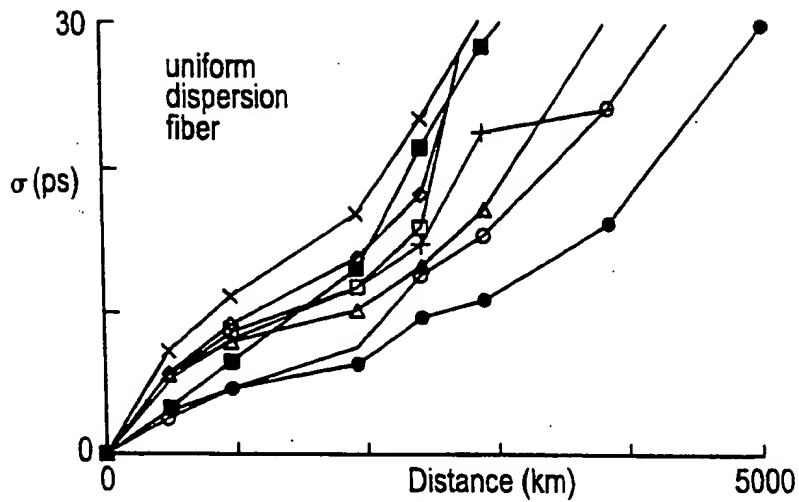   12.   An apparatus as claimed in claim 11, wherein said dispersion-managed fiber system includes a normal dispersion fiber connected to an anomalous dispersion fiber.

       13.   An apparatus as claimed in claim 11, wherein said
5   dispersion-managed fiber system includes a filter connected to a normal dispersion fiber.

       14.   An apparatus as claimed in claim 11, wherein said dispersion-managed fiber system includes an amplifier, a filter connected to said amplifier, a normal dispersion fiber,
10   and an anomalous dispersion fiber connected to said normal dispersion fiber.

       15.   An apparatus as claimed in claim 11, wherein said dispersion-managed fiber system includes an amplifier, a filter connected to said amplifier, a normal dispersion fiber
15   having a length of approximately 35 km, and an anomalous dispersion fiber having a length of approximately 5 km and connected to said normal dispersion fiber.

       16.   An apparatus as claimed in claim 11, wherein said dispersion-managed fiber system is adapted for use in time
20   division multiplexing.

17.   An apparatus as claimed in claim 1, wherein said dispersion-managed fiber system includes alternating-sign dispersion management.

18.   An apparatus as claimed in claim 6, wherein said dispersion-managed fiber system includes alternating-sign dispersion management.

19.   An apparatus as claimed in claim 11, wherein said dispersion-managed fiber system includes alternating-sign dispersion management.

20.   An apparatus as claimed in claim 1, wherein said dispersion-managed fiber system includes both standard and dispersion-shifted fibers.

FIG. 1A
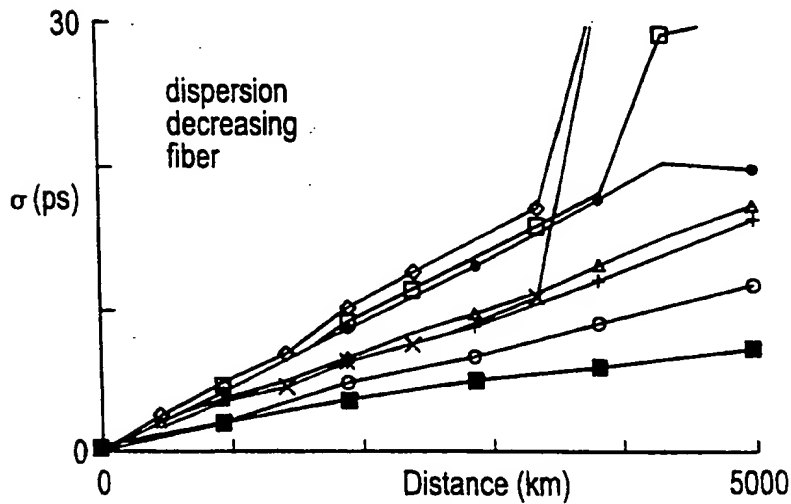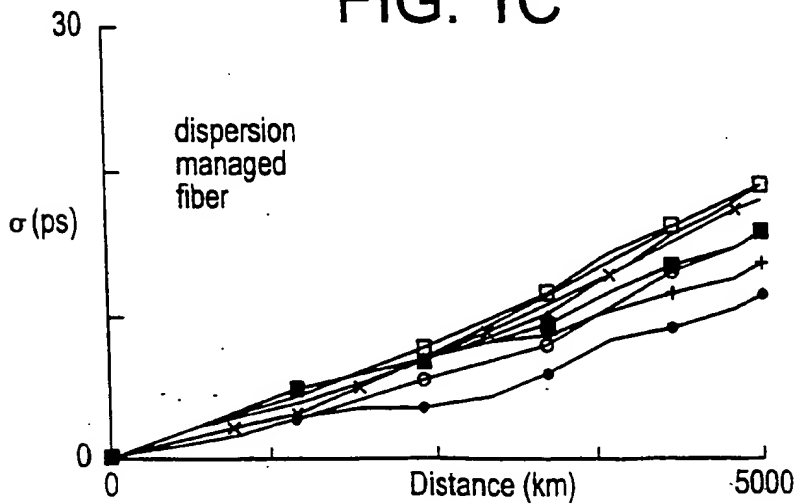
uniform
dispersion
fiber

σ (ps)

Distance (km)

FIG. 1D

FIG. 1B

dispersion
decreasing
fiber

σ (ps)

Distance (km)

channel
number

⊖— 1
⊟— 2
◇— 3
⨯— 4
+— 5
△— 6
●— 7
■— 8

FIG. 1C

dispersion
managed
fiber

σ (ps)

Distance (km)

FIG. 2

FIG. 3A

uniform dispersion fiber

FIG. 3B

dispersion decreasing fiber

FIG. 3C

dispersion managed fiber

FIG. 4A

uniform dispersion fiber

FIG. 4B

dispersion decreasing fiber

FIG. 4C

dispersion managed fiber

FIG. 5A

uniform
dispersion
fiber

σ (ps)

Distance (km)　　5000

FIG. 5B

dispersion
decreasing
fiber

σ (ps)

Distance (km)　　5000
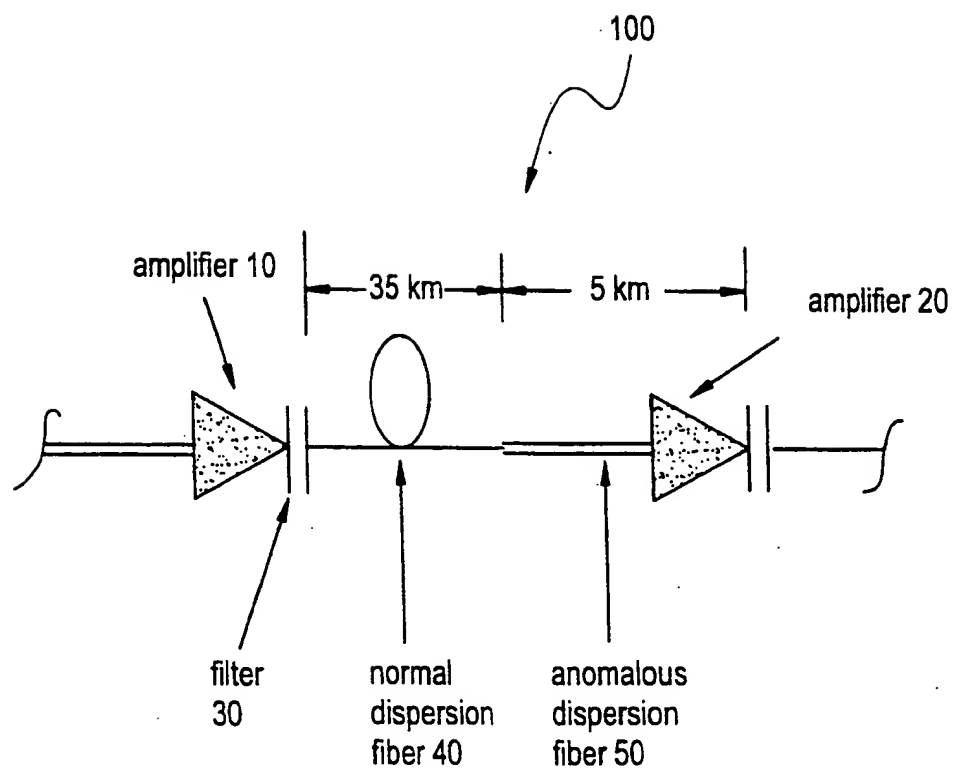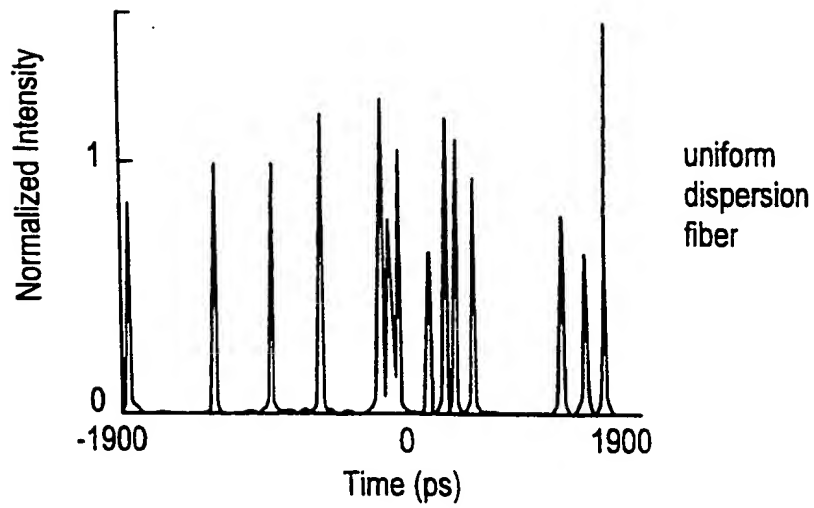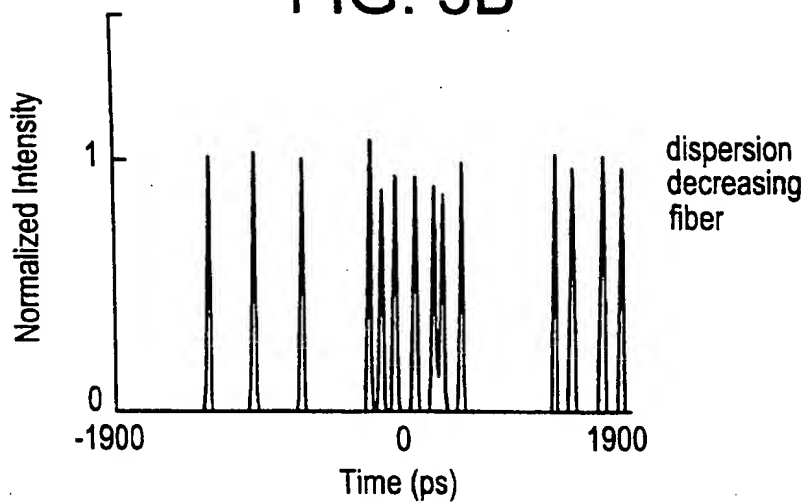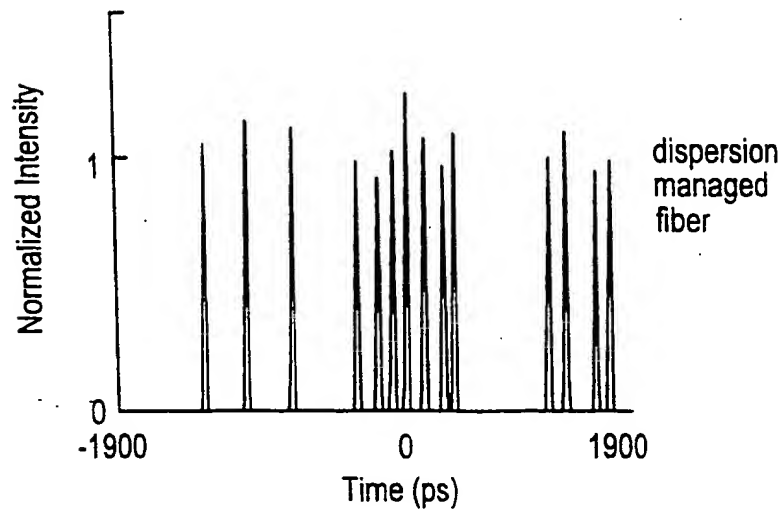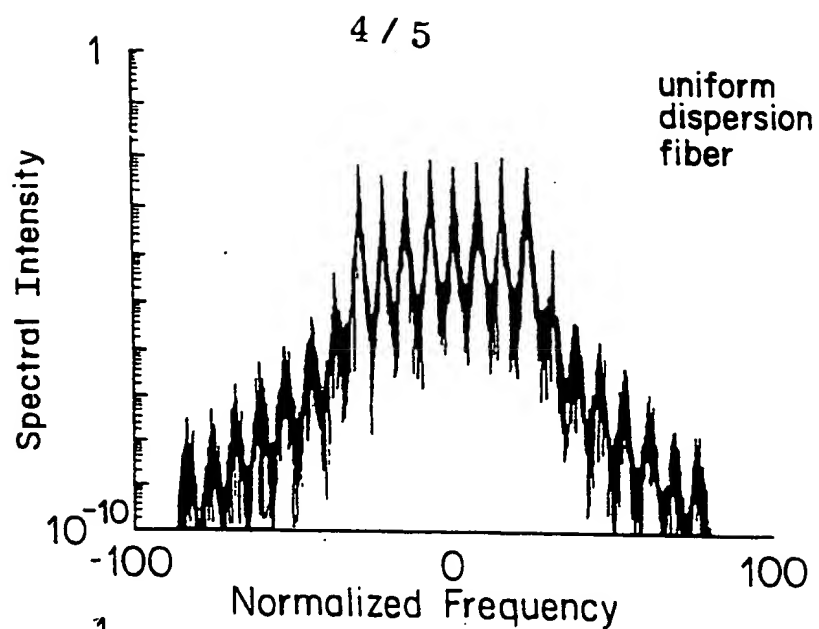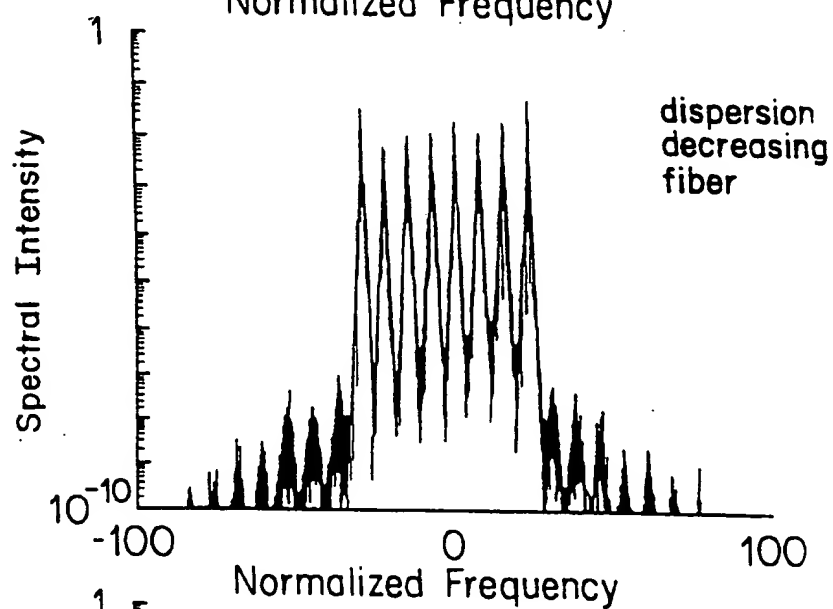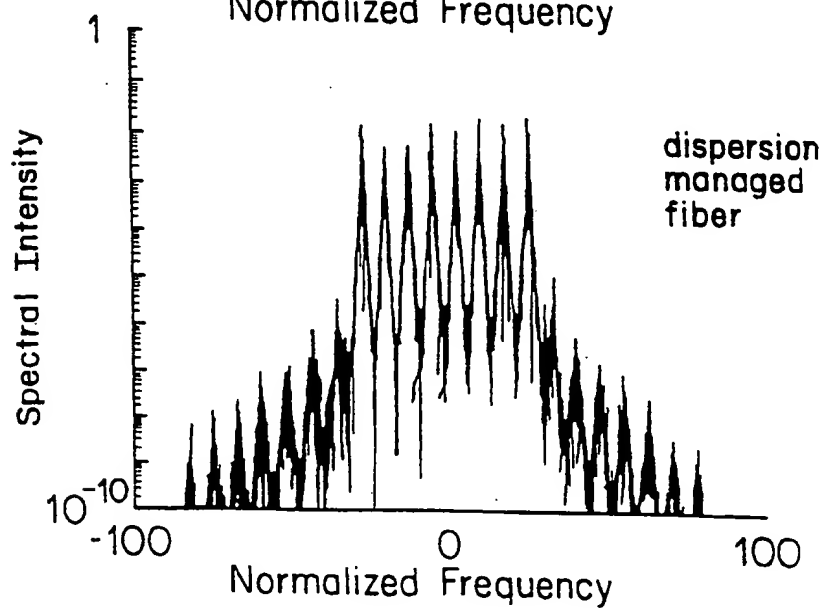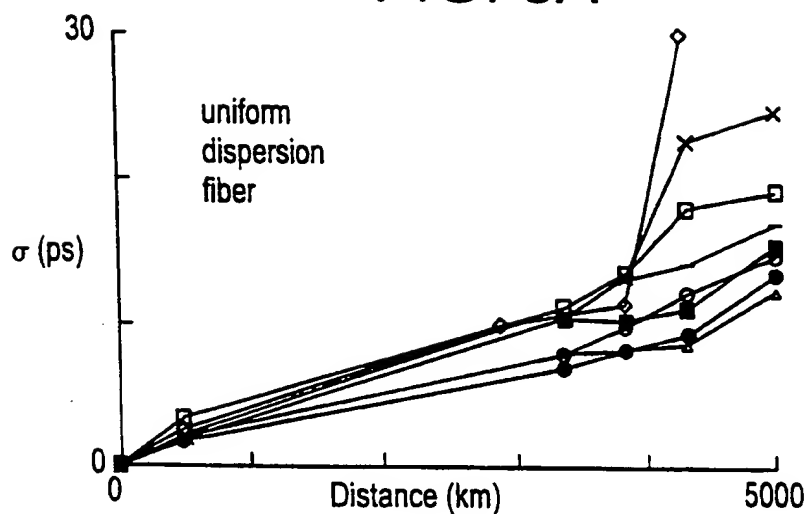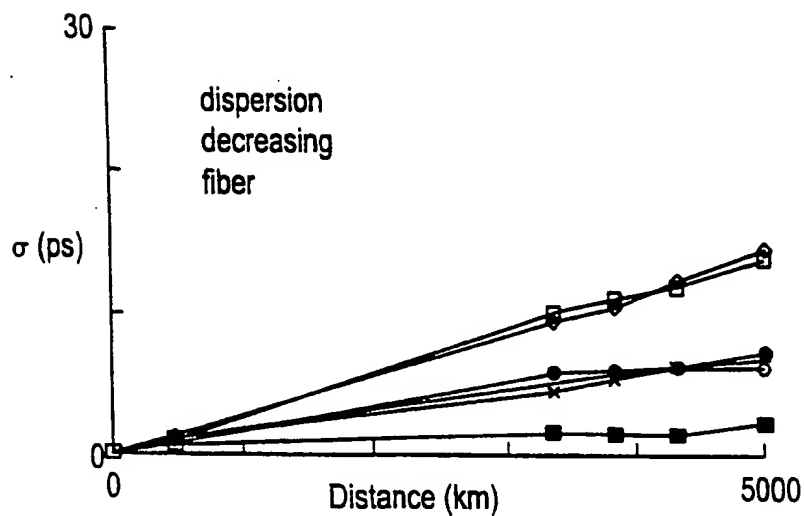
channel
number

1
2
3
4
5
6
7
8

FIG. 5C

dispersion
managed
fiber

σ (ps)

Distance (km)　　5000
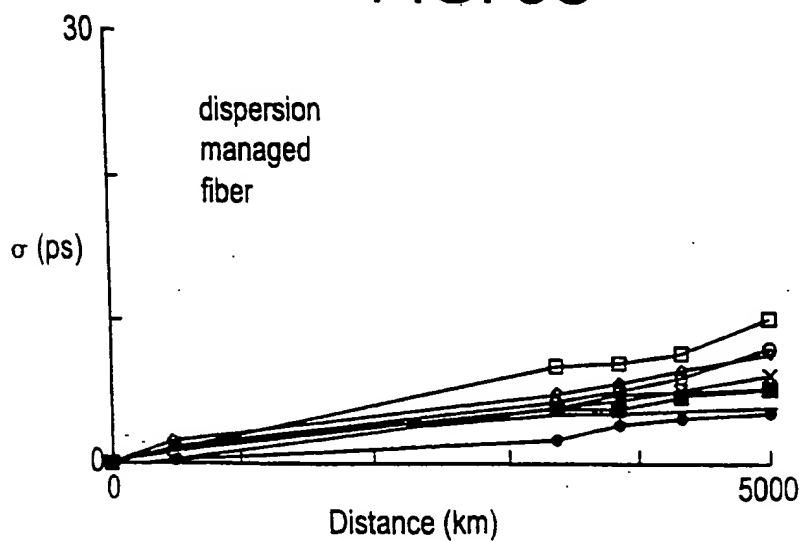
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04B 10/00
US CL : 359/161,160,173,188,179

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 359/161,160,173,188,179

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ––– Y	DEVANEY, J.F.L. ET AL., Modelling WDM Soliton Transmission in Dispersion-Managed Systems, IEE, 06 February 1997, pages 1-4. London, UK.	1-2,6-7,11-12,20 ------------ 3-5,8-10,13 -19
X	HASEGAWA, A. ET AL., Reduction of Collision-Induced Time Jitters in Dispersion-Managed Soliton Transmission Systems, Optics Letters, 01 January 1996. Vol. 21 , No. 1. Pages 39-41.	1,6, and 11
Y	MATSUZONO, T. ET AL., Transmission Characteristic Improvement of Two-Channel Wavelength Division Multiplexed Solitons by Controlling Initial Time Offset, LEO '96 Conference Proceeding 9th Annual Meeting IEEE Lasers and Electro-Optics Society, 18-19 November 1996. Boston, MA.	3-5,8-10,13-19

☐ Further documents are listed in the continuation of Box C.   ☐   See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance		
"E"	earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)		
"O"	document referring to an oral disclosure, use, exhibition or other means	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 APRIL 1998	1 9 JUN 1998

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	KINFE-MICHAEL NEGASH
Facsimile No. (703) 305-3230	Telephone No. (703) 305-4932

Form PCT/ISA/210 (second sheet)(July 1992)★